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THE COST OF ADVANCED WEAPONS

David Novick

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## THE COST OF ADVANCED WEAPONS

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I have been asked to talk again about the cost of advanced weapons. Much of what I can say has been said before. However, there has been a tendency to look at pieces of the problem rather than the whole, with the result that conclusions have sometimes been overdrawn, and a series of partial cures suggested.

For example, we have frequently heard the statement that "we are spending ourselves into national bankruptcy." And, since defense or national security takes more than 50 per cent of our total national budget, defense spending for new and exotic weapons has been charged with the responsibility for our national financial problems.

And, dealing with specifics, we have all heard it said that complexity and lack of reliability are the twin causes of the current high cost of new weapons. The statement has been made that if unnecessary complexity could be eliminated and reliability improved through better quality assurance the cost per pound of payload in orbit might be reduced to \$100 or less. Other charges have laid the high costs at the door of labor, the Military Services, and the contractors.

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It is my belief that to a large extent at least, the high cost of advanced weapons basically lies in the nature of the weapons themselves. This is not to say that cost savings are not possible. Rather, it is essential to first understand the nature of the weapons and then to look at some of the factors which now contribute to high costs.

In this discussion, we will therefore consider (1) The factors which are increasing the cost of new weapons; (2) The counterbalancing factors, which are holding total defense expenditures more or less level when expressed in terms of constant dollars; (3) Some probable future trends; and, (4) The first attempts to develop a program budget for national security.

As a point of departure, however, it would be well to consider for a few minutes the categories of cost which are involved in any discussion of the program cost of new and advanced equipment.

These are:

(1) Research, development, test and evaluation, which includes all the expenditures associated with bringing a system to a point where it is ready for introduction into the operational force. This involves, for example, proving grounds, the Atlantic and Pacific Missile Ranges, test vehicles, related GSE and facilities and all of the activities associated with test and evaluation.

(2) Initial investment, which includes all the expenditures required to introduce a new capability into the operational force, including initial procurement of major equipment and components of the system required to make it combat ready -- i.e., basic facilities, ground environment equipment, initial stocks, initial training of personnel, etc.

(3) Annual operating costs which includes expenditures for maintaining

and operating a system which has been introduced into the active forces. This includes personnel pay, allowances, training of personnel replacements, maintenance (including depot maintenance), POL, equipment replacement and the like.

These general cost categories correspond to the life cycle of a new weapon system -- development, introduction into the operational inventory, and operation until phaseout.

A full understanding of the nature of these categories is important when considering the factors which play a large part in increasing the cost of new weapons and the shifting pattern of resource demands. Over the years since 1952, research, development, test and evaluation, including basic research and technical development programs, as well as development of weapons and support systems, have taken an increasing share of the defense dollar.

The R&D percentage rose from an insignificant proportion in the 1940's to slightly less than 7 per cent in fiscal 1952 and to about 20 per cent in fiscal 1961. At the same time, percentages attributable to operating costs remain about constant (50 per cent) and the percentage for investment declined to about 30 per cent. (Charts I and II)

It might be asked at this point, why does research and development take an increased share of the defense dollar and what effect does that increase have on the cost of advanced weapons. Actually, the increased emphasis on research and development stems in large measure from the thermonuclear breakthroughs of the mid-50's and the new requirements which that breakthrough generated for intercontinental ballistic missiles, high Mach number aircraft and now for warning devices, communications equipment, and defensive

PERCENTAGE DISTRIBUTION OF USAF EXPENDITURES  
R AND D, INVESTMENT AND OPERATIONS  
(FY 1951 - 1961)

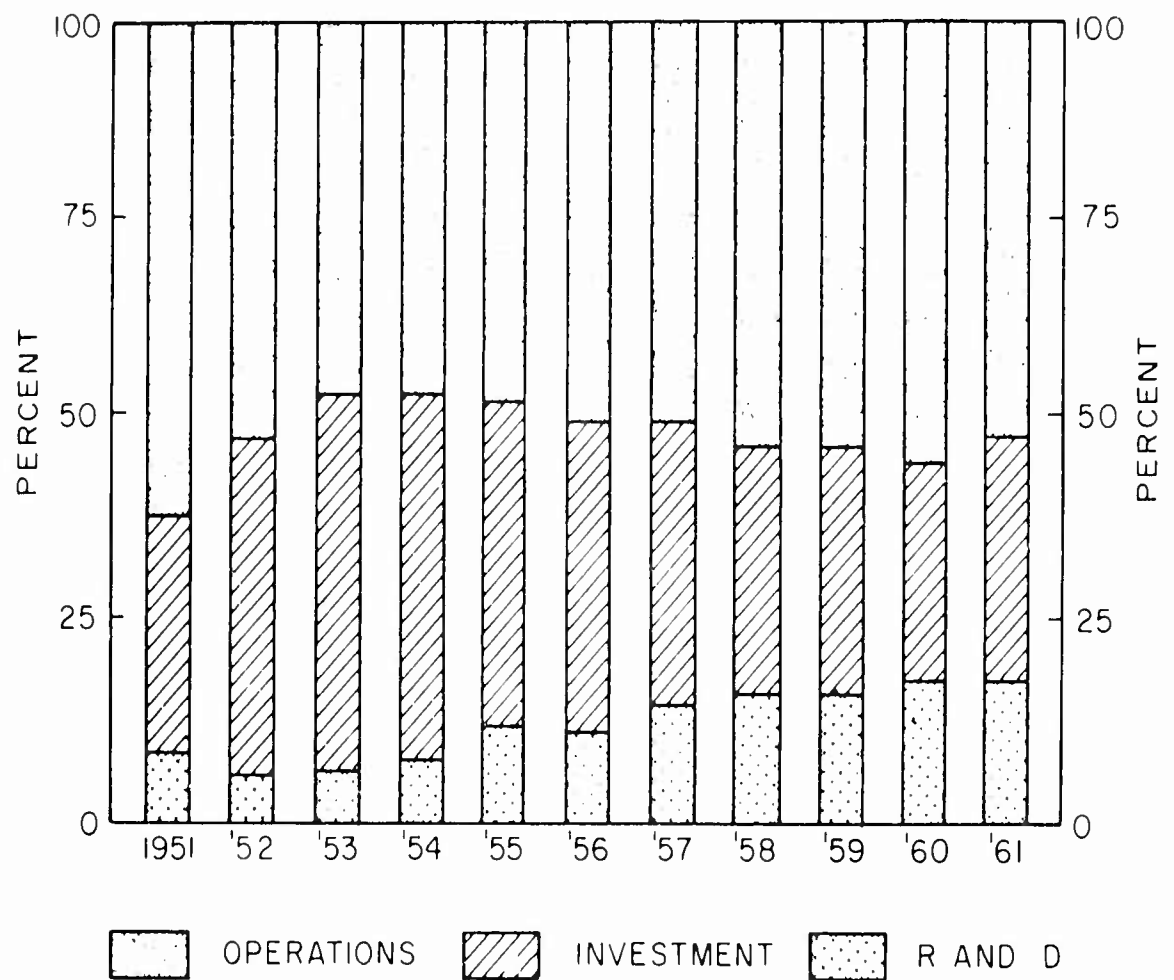


CHART I

PERCENTAGE DISTRIBUTION OF WEAPON SYSTEMS EXPENDITURES  
R AND D, INVESTMENT AND OPERATIONS

SYSTEM	R&D	INVESTMENT	OPERATIONS	TOTAL
B-36	2%	25%	73%	100%
B-47	3	47	50	100
B-52	5	43	52	100
B-58	28	45	27	100
F-86	1	23	76	100
F-100	3	39	58	100
F-105	21	49	30	100
SM 65 (Atlas)	36	33	31	100
SM 68 (Titan)	41	34	25	100
SM 80	15	49	36	100

CHART II

missiles to protect military installations and at least part of the population from the ICBM and high speed aircraft. Each of these, in turn, helps to generate still newer requirements -- the latest being the need to move out into space with communications, navigation, and DYNASOAR, and still more advanced future equipments.

The second part of the question -- what effect does the increased emphasis on research and development have on advanced weapons costs -- is somewhat more difficult to answer. To a large extent, the new equipments are the product of the laboratory rather than of the production line -- the unknowns and variables are very large and the new weapons are very complex and very expensive.

Some idea of the current complexity of equipment can be drawn from the statement of Colonel William H. Congdon of Electronic Systems Division in a speech before the Aerospace Writers Association last spring. He noted that the guidance package for Titan contains about 100,000 electronic parts while System 412 L (Air Weapons Control System) contains 7 million parts in the data system alone.

This complexity is of two types -- the first, a product of the ever higher performance characteristics imposed on our new system and, the second, a design complexity which to some extent may be mitigated.

But regardless of its reason complexity is expensive not only in the long leadtime between drawing board and the delivery of new equipment to the combat forces but also in the cost or resource demand of these new weapons.

To illustrate, it might be well to consider for a moment the old story of the Wright Brothers first aircraft. Reduced to basics, its only subsystem was man. It cost about \$25,000. It was succeeded by the early

World War II fighters which cost about \$150,000 a copy and later by the Century series aircraft which were priced, generally speaking, at more than \$1 million a unit.

Each succeeding generation of aircraft has had two things in common -- it has more performance and therefore more subsystems (complexity) and costs more in dollar resources. Some of the less obvious costs involve the work of marrying the subsystems into an effective whole -- systems integration and the new and complex training devices which take the place of the "seat-of-the-pants training" of earlier days.

These are examples of what I mean when I say that to a large extent the high cost of new weapons basically results from the nature of the equipments themselves.

With the higher performance characteristics and resulting complexity, plus the strange new environmental conditions in which our new weapons will operate, comes a new demand for reliability. We can ill afford ICBMs blowing up on the launching pad because of a bad solder joint, a malfunctioning or badly designed transistor, or the failure of documentation to catch up with modification of a component.

The result has been a new (and some people think too great an) emphasis on reliability. In addition, expensive and extensive test programs are required. General Bernard A. Schriever, Commander of the Air Force Systems Command, has compared the test program to an "ice-berg" only one per cent of which, in the shape of several dozen tests, has public visibility. The rest is not apparent. The greatly

expanded test program has forced the expansion of test facilities, including automatic checkout equipment and the like, both in contractor and government plants, which again add to the cost of an advanced equipment program.

In dealing with more or less conventional aircraft, you will recall, the plan used to be to build one so-called X model and two or three Y models. More recently, orders for test aircraft have been much larger with many of these later being converted to operational aircraft.

This situation does not and cannot exist in the case of missiles and space craft which are essentially one-shot operations.

But hardware is only a part of the increased test cost. Estimates made by NASA indicate that it takes about six weeks to complete checkout at Cape Canaveral both in the hangar and on the launching pad before one of the big vehicles is ready for firing. William A. Flemming of NASA, writing in Astronautics Magazine last June, said:

A brief look at a few figures will indicate clearly just how much our present techniques are costing us. The Thor-Agena B, Atlas-Agena B and Centaur launch vehicles require a field force at the launch site of several hundred men. It takes six to eight weeks -- using current procedures -- to check out the thousands of functions of the many vehicle components (even after similar tests have been run in the manufacturer's assembly plant.) The Saturn field force will be even larger, and we estimate it will take longer to complete Saturn's checkout prior to flight. Translated into dollars, the cost of the field force engaged in preparing a vehicle for launch mounts into millions of dollars per flight. Add the field-force expense of the cost of the equipment and facilities at the Cape necessary to support a field crew in conducting its tasks and the resulting total becomes truly staggering.

This does not take into consideration tests now being run in manufacturing plants and plants of subcontractors and suppliers. It also fails to take into account, the capital costs in the way of new facilities and

equipment required both in the factory and on launch pads as well as the monitoring devices required to assure that the missile or space vehicle is actually functioning as directed after launch. And, this for testing, not manufacture.

#### SOME SPECIFIC FACTORS AFFECTING COSTS

With this generalized picture in mind, some specifics involved in the steady increase in cost of new equipment can be discussed. The first is labor, the cost of which has increased steadily since 1954. (Charts III and IV)

Even more important perhaps is the change in the labor mix. The day of Rosie the riveter is almost done. In her place comes the highly skilled engineer and mechanic and the automated tape controlled machine. Tape machines cost as much as \$10 an hour to stand idle on the plant floor. But these are essential to meet requirements imposed by the high performance characteristics and close tolerance required in the fabrication and assembly of our advanced weapons.

A second cost factor is material. As we seek higher speeds and altitudes, we require not only new and complex equipment but also new materials, which in turn require new production and fabrication techniques. I have taken as an example the difficulties inherent in the production of the Mach 3 transport. But much the same costs are involved in the production of our new weapons.

Whereas aluminum has been the standard aircraft material, we talk now of steel, titanium and titanium alloys and even beryllium for our high-speed aircraft and missiles. Costs of materials vary depending on gauge, form and quantity and, therefore, a range of prices is shown for these materials. (Chart V)

INDEX OF ANNUAL AVERAGE WEEKLY EARNINGS PER NONSUPERVISORY  
WORKER IN THE AIRCRAFT INDUSTRY AND PRICE  
OF AIRCRAFT MATERIALS (1954=100)

	Index of Av. Weekly Earnings per Worker	Av. Weekly Hours	Index of Av. Price Aircraft Materials
1945	63.9	45.7	51.6
1946	61.4	40.6	57.9
1947	63.4	39.8	71.6
1948	70.8	41.1	79.5
1949	73.7	40.5	81.5
1950	78.9	41.4	84.5
1951	89.1	43.3	93.7
1952	93.6	42.6	94.7
1953	96.6	41.3	98.8
1954	100.0	40.9	100.0
1955	105.1	41.2	103.8
1956	111.5	41.8	109.2
1957	112.4	40.7	119.1
1958	119.2	40.4	120.4
1959	124.8	40.2	123.4
1960	129.9	40.7	125.2
1961			

SOURCE: Employment and Earnings and Wholesale Prices and Price Indexes,  
Bureau of Labor Statistics, U. S. Department of Labor, Washington, D. C.

CHART III

INDEX OF ANNUAL AVERAGE WEEKLY EARNINGS PER  
NONSUPERVISORY WORKER IN THE AIRCRAFT INDUSTRY  
AND PRICE OF AIRCRAFT MATERIALS (1954 = 100)

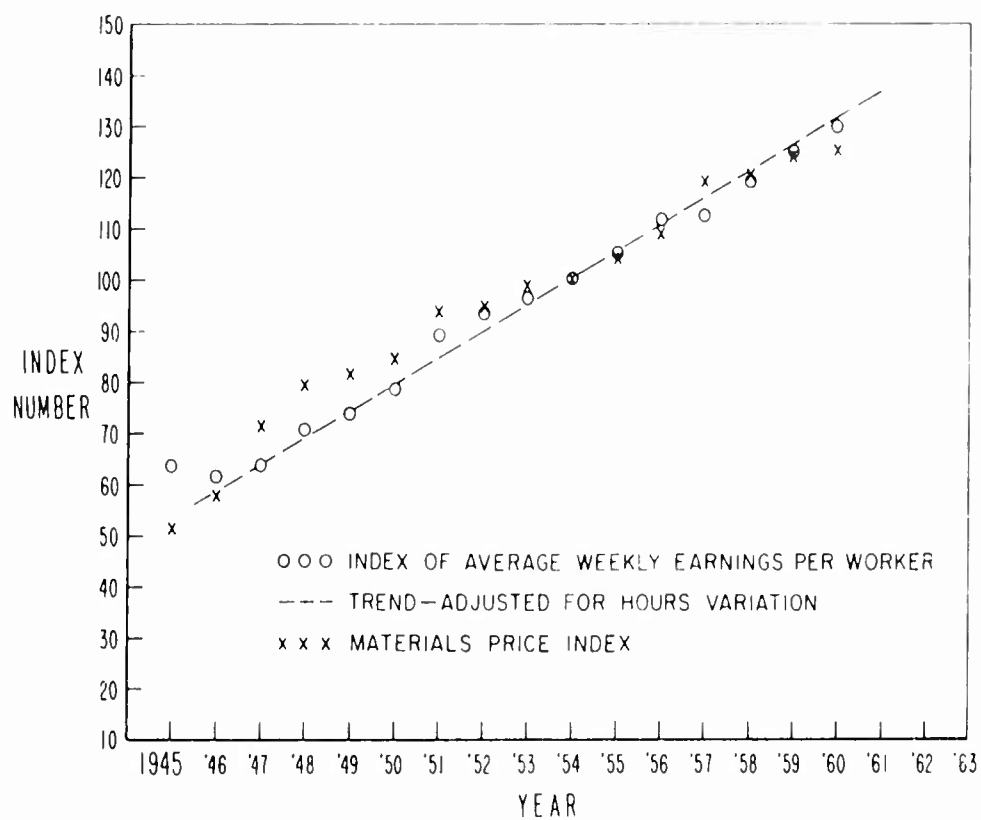
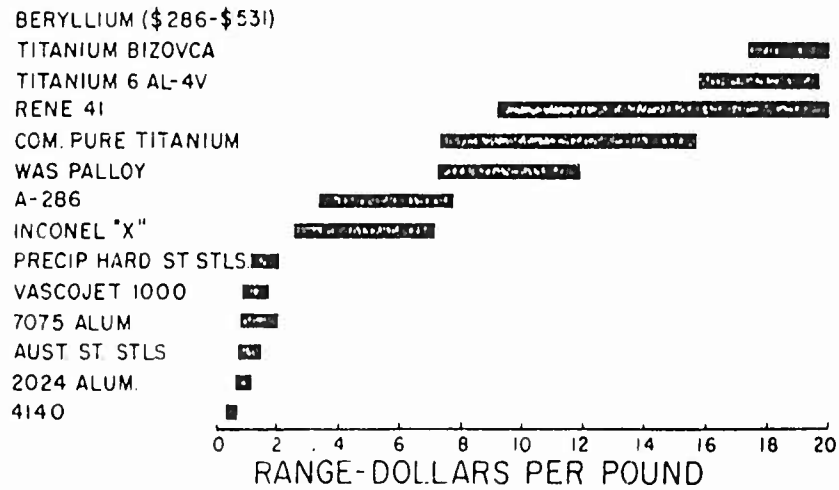


CHART IV

### COST PER POUND-SHEET STOCK

SHEET THICKNESS RANGE • 010 THRU 050  
QUANTITY • 10,000 POUNDS



(FROM PAPER BY E A GREEN 9 OCT 1961)

### CHART V

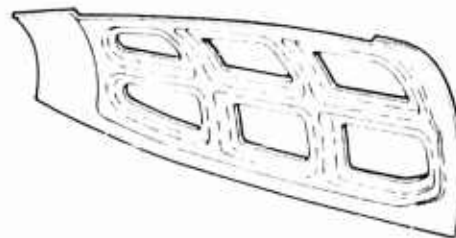
High cost of these materials is only one factor. There is, in addition, the problem and the cost of learning to fabricate and to assemble them into usable structures. All of the materials have one characteristic in common. They are more difficult to form, machine, forge, and produce.

For example, many of the metals require hot forming. The cost of forming an aluminum deep-drawn part, such as a stamped inner frame, is compared in the following with the cost of forming other materials. This shows a cost increase of approximately twofold for the hot-formed hard materials. (Chart VI)

Machining of these parts is also a problem. It has been estimated that steel or other hard alloy ribs and fittings manufactured from forgings would require additional machining over aluminum alloy parts. Since it is expected that these new materials will take from 20 to 30 times as long to machine as aluminum alloys, increases in machining costs in the order of 3000 to 1 are expected -- thus we need a substantial breakthrough in the art of machining if the goal of a Mach 3 transport is to be reached.

While I have used the illustration of the Mach 3 transport, what I have said applies equally to new and advanced military equipment. The need for new materials generated by heat and weight constraints and environmental conditions is coupled with the need to learn new techniques for making them. In addition, the state-of-the-art must be pushed for forming and fabricating methods needed to provide close tolerance, reliable bits and pieces which are assembled into new missiles, rocket motors, electronic equipment and the like -- and, this whole process is costly of resources of all kinds whether expressed in terms of dollars, manpower or new capital equipment.

# RELATIVE COST OF FORMING VARIOUS MATERIALS



FORMING METHOD	MATERIAL	LABOR COST	TOTAL TOOLING	COST EACH INCL. LABOR & AMORT. TOOLING
DOUBLE ACTION DIE	VASCOJET 1000 AM 350	\$18	\$5500	\$568
DOUBLE ACTION DIE (HEATED)	COM. PURE TITANIUM TITANIUM 6AL-4V	\$23	\$6850	\$708
DROP HAMMER	7075 ALUMINUM	\$15	\$3840	\$399
EXPLOSIVE FORMING	VASCOJET 1000 AM 350 7075 ALUMINUM	\$13	\$3760	\$389

0 400 800

(FROM PAPER BY E A GREEN 9 OCT 1961)

## CHART VI

We have seen that we are pushing the state-of-the-art in many different ways, and have begun to see, I think, why advanced weapons become progressively more expensive. However, a specific example may be in order and I have taken one from the electronics industry.

It has been estimated that more than half the cost of subsystems is due to rejects and reworks from inspection. When subsystems are combined into systems, their adjustment into a compatible whole usually requires many times the labor involved in the individual system assembly. Where a subsystem is well within the state-of-the-art, it is estimated that preset cost standards established by a company will be reached by the 50th unit. However, when the state-of-the-art is pushed, the estimated standards are frequently not met until the 250th unit. And sometimes when the state-of-the-art is pushed hard, standard costs are not reached until more than 1000 units have been made.

While these statements are derived from the production of a single but experienced component and subassembly manufacturer, the pattern appears to be the same throughout the electronic industry. Production labor amounts to about 25 per cent of total employees. Other direct labor charges are made by engineers working on subsystems, planners and the like. A rough estimate is that indirect labor costs run double the direct labor.

In order to picture the direct labor and materials curves and relationships, a simplified case is shown in Chart VII. Here, it was assumed that the standard was reached at the 100th unit. Some improvement in inspection and rework was also assumed. The special case shows components specially made for the subassembly and a one to one ratio. Any other assumption would flatten the component curve. In this case, the shape of the total curve is about as steep as could be expected.

ELECTRONIC EQUIPMENT COST ESTIMATE UNIT CURVES

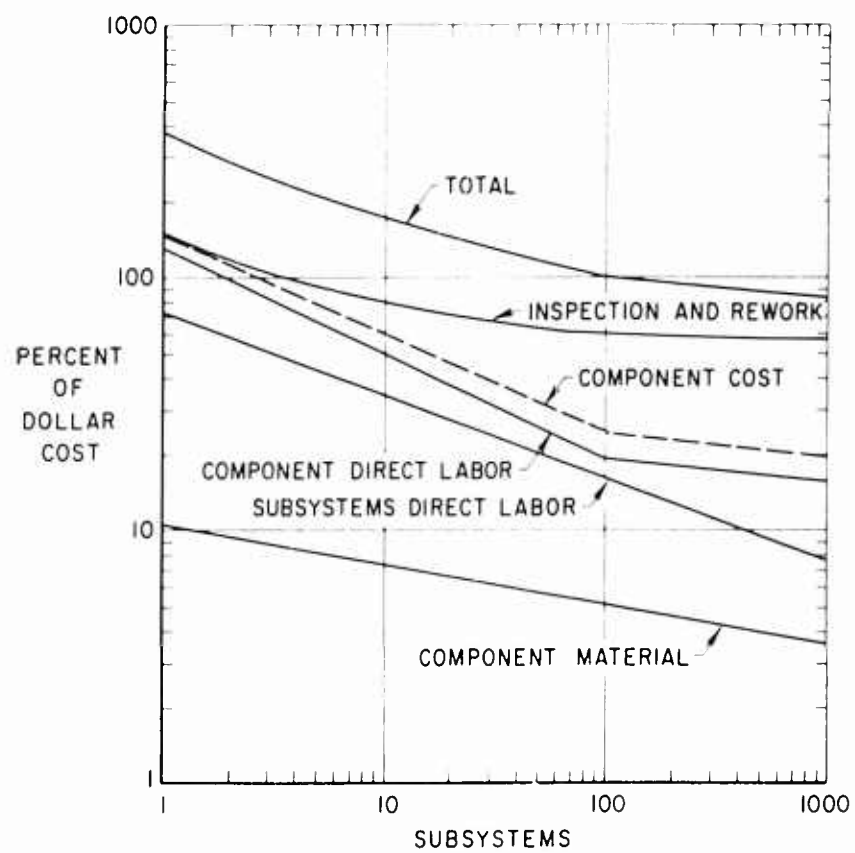


CHART VII

The case illustrated is well within the state-of-the-art. Most electronic equipment for missiles pushes the state-of-the-art. Inspection and rework costs would be heavier and the standard would not be reached until a larger quantity was produced.

The subsystems are then combined into a system and adjusted into a unit. This is a very unpredictable curve, tending to average nearly flat. (Chart VII)

We have seen thus far that the cost of advanced weapons has steadily climbed even though total defense expenditures have remained more or less constant. This, on its face, would seem to be a contradiction in terms. How can dollar expenditures remain more or less level and the cost of advanced weapons continue to rise?

The answer in essence lies in the increased effectiveness of the new weapons, thus requiring fewer units of new systems to do the work that large numbers did during World War II. The days of ordering thousands of bombers and fighters seem over. Basically this is because one or a few pieces of equipment can now do an equivalent or better job.

In addition to increased effectiveness, other factors tend to reduce the current military requirements. These include:

- (1) The rapid rate of technological change. While this makes for increased research and development expenditures generally, the obsolescence factor tends to reduce the quantity put into inventory and therefore the total investment (initial inventory) and operating cost for a particular system.

- (2) Recognition of the complementary nature of weapons and forces. More important than the number of air vehicles in any one given system is the overall mix.

I have been talking about the current situation and the recent past. We may go back into the numbers business with the decision to maintain both a central war deterrent and a capability to handle limited or brush-fire wars with conventional weapons. President Kennedy said in his State of the Union address: "We have rejected an all-or-nothing posture which would leave no choice but inglorious retreat or unlimited retaliation."

#### A LOOK AHEAD

There is every reason to believe that we will continue to push the state-of-the-art in the years ahead. Recently, the drive has been towards the Moon and outer space. The DOD FY 1963 budget request includes \$5,667 million for that part of the R&D program not directly identified with elements of other programs. This is an increase of \$940 million over FY 1962.

Not only the Defense Department but NASA is pushing the state-of-the-art. Since its beginning in 1958, NASA has been doubling its dollar requirement annually, according to James E. Webb, its Administrator. To get to the Moon quickly and relatively inexpensively, Mr. Webb told a luncheon meeting of the American Ordnance Association recently, it will be necessary to establish the feasibility of satellite docking techniques which would permit the launching of the moon craft and space boosters separately and then joining them together while in orbit around the earth.

If this technique cannot be developed, time and dollars will be required for the development of a full-size Nova rocket. There is little doubt that as we continue to move out into space and learn more about the environment, we will have to write new pages in the textbook and then invent new materials and develop, form, fabricate and assemble new vehicles and their components.

Defense Secretary Robert McNamara, in his first appearance before the Senate Armed Services Committee this year, stated, "Looking beyond the next few years, there will clearly be a need for new strategic retaliatory systems. Not as clear are the kinds of systems which will be required in that time period."

In dealing with the future need for conventional weapons, the Secretary said, "...We must have:

- (1) Adequate combat-ready conventional forces.
- (2) Airlift and sealift to move these forces promptly to wherever they may be needed.
- (3) Tactical air support for the ground forces.
- (4) Sea forces to ensure control of the seas.
- (5) Balanced and properly positioned inventories of weapons, equipment and combat consumables to ensure that these forces have what they need to fight effectively."

What the new systems and equipment will be is difficult to predict at this time, although a decision has been made to get on with the development of the TFX tactical fighter which uses a variable geometry wing and turbo-fan engines, and with another version of the F<sup>4</sup>H which will be redesignated the F<sup>4</sup>C by the Air Force.

There is, of course, no way now of predicting what the scientists may turn up in their laboratories in the years ahead which will revolutionize again the art of weaponry. The only thing which now seems to be certain is that the search for new knowledge and new techniques will continue, forcing changes not only in our equipment but in our methods of deployment and use of our new weapons and our management of weapon programs.

THE FIRST ATTEMPTS BY THE DEFENSE DEPARTMENT TO DEVELOP A PROGRAM BUDGET

Since I accepted your invitation to speak to you on the cost of advanced weapons, President Kennedy, as you all know, has sent the budget for FY 1963 to Capitol Hill. It is not my purpose to discuss the details of even the national security aspects of that formidable document. Instead, I want to discuss some of the changes in the budget structure made by Defense Secretary McNamara.

The new budget represents a first attempt at "program budgeting." It is cast in terms of the end use to which our weapons will be put -- i.e., strategic retaliatory forces -- continental air and missile defense forces -- general purpose forces (including tactical ground, air and sea forces) -- sealift and airlift -- reserve and National Guard programs -- research and development (unrelated to a specific weapon) -- and, general support (not directly allocable to a mission). In addition, a new section covers the civil defense effort for which the Defense Department is now responsible.

The program packages are, in turn, made up of various subpackages and elements, designed to show the decision-maker and the planners the alternate ways of accomplishing a given mission and the resource cost of each choice. The rationale of these changes and how they work out are perhaps best described in the statement of Defense Secretary Robert McNamara before the Senate Armed Services Committee. Mr. McNamara said: "Because of the great technical complexity of modern-day weapons, their lengthy period of development, their tremendous combat power and their enormous cost, sound choices of major weapon systems in relation to military tasks and missions have become the key decisions around which much else of the Defense Department revolves. But the full cost implications of these decisions, present and

future, cannot be ascertained unless both the programs and their cost are projected over a period of years, ideally over the entire life cycle of the weapon system. Since such long-term projections are very difficult to make with any degree of precision, we have fixed on a five-year period, which is short enough to assure reasonably accurate estimates and long enough to provide a good approximation of the full cost.

"I am sure you realize that the further into the future we project the programs, the more provisional they should be considered. As we move along, changes will have to be made in the projected programs, and entirely new projects, the need for which cannot now be clearly foreseen, will have to be added. As you well know, all such long-term projections tend to have a downward bias, simply because we cannot see clearly the course of future developments.

"These uncertainties are even more pronounced in the 'costing' of the forward programs. Although we have costed the programs projected through FY 1967, we do not yet have a very high degree of confidence in our estimates beyond 1963, since they have not been subjected to the detailed and rigorous review accorded to the 1963 and current year estimates. Therefore, I will not attempt to project program costs beyond 1963. Perhaps next year, after we have perfected our costing techniques and gained greater experience with the new procedure, we will be able to develop more reliable cost estimates for the years further out in the future."

#### CONCLUSION

We have seen that the cost of our new weapons is likely to continue to increase over time, even though counterbalancing factors may hold defense expenditures close to the level of the last few years. We have looked

at some of the factors responsible for rising costs as well as some of the factors which have tended to hold total defense expenditures more or less constant.

We have seen also that our laboratories are providing more than one way of getting a job done. The problem immediately ahead therefore will be to provide the machinery which will allow the planner and decision-maker to choose among the alternative methods provided by the laboratories and research centers. This will require an increasing capability to project the cost of these new weapons over their life cycle and to decide whether increasing effectiveness is worth the added resource cost. This basically is the aim of the program budgeting effort in the Defense Department and the aim of the effort of USAF, especially AFSC, to develop an improved costing capability. The goal is to offset some of the increase in cost by improved decisions made possible by better information.